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Probing For New Physics In J/Ψ Decays

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Abstract

Beijing Spectrometer (BES) at Beijing Electron Positron Collider (BEPC), IHEP has accumulated 2.5 $\times 10^7$ J/Ψ and plans to increase the number to $10^8 \sim 10^9$ in the near future. In this paper I review and summarize the recent studies on the possibilities of probing for new physics at BES. This includes the theoretical works on and experimental attempt performed at BES in searching for flavor changing neutral current, CP violation and lepton flavor violation in the processes of J/Ψ decays.

1 Lepton flavor violating J/Ψ decays

The J/Ψ rare decay processes $J/\Psi \ \rightarrow \bar{l}l'$ ($l,\ l' = \tau,\ \mu, e$) conserve total lepton number, but violate the individual lepton numbers. In the standard model the lepton flavor symmetries are conserved, but speculated to be violated in many extensions of the standard model, such as supersymmetric standard models, left-right symmetric models and models where electroweak symmetry is broken dynamically. Recent Super-Kamiokande experiment results indicate that neutrinos have non-vanishing masses, mix with each others and consequently that lepton flavor symmetry and/or lepton number symmetry are broken symmetries. In cosmology mystery of matter and antimatter asymmetry might be understood in terms of the brokendown of the lepton number symmetry together with the non-perturbative effects (Sphaleron) of the standard electroweak theory.

There has been a lot of studies both theoretically and experimentally on testing the lepton flavor conservation law. At present we have various bounds listed in the particle data book from μ decays, τ and Z gauge boson decays[1]. With a large sample of J/Ψ, BES will be able to make an additional experimental searching for lepton flavor violation.

To estimate the branch ratio of lepton flavor violating J/Ψ decays allowed by the current experimental data, Peccei, Wang and I[2] took a model-independent approach to new physics and introduced a four-fermion contact interaction

$$\frac{4\pi}{\Lambda^2}\bar{c}\gamma^{\mu}c\ \bar{l}\gamma_{\mu}l', \tag{1}$$

where Λ is the new physics cutoff. This effective operator is forbidden in the standard model, however will be generated in theories where lepton flavor is not conserved, such as the minimal supersymmetric standard model with and/or without R parity, models with large extra dimension[3]. Therefore, any observed signal is a direct evidence for non- standard physics and will improve our understanding of flavor dynamics, especially in the lepton sector.

There is no direct experimental limit on Λ in (1). However, at one-loop, attaching the neutral

gauge boson Z to the charm quark loop generates an effective coupling of Z to $\bar{l}l'$. From the limits given in the particle data book on $Br(Z \to \bar{l}l')$[1], we obtained the lower bounds on the branch ratio of the J/Ψ decay into leptons:

$$Br(J/\Psi \to \tau^+ e^-) < 2.7 \times 10^{-5}; \tag{2}$$

$$Br(J/\Psi \to \tau^+ \mu^-) < 4.9 \times 10^{-5}; \tag{3}$$

$$Br(J/\Psi \to \mu^+ e^-) < 8.3 \times 10^{-6}. \tag{4}$$

Recently Nussinov, Peccei and I[4] have examined "unitarity inspired" relations between two- and three-body lepton flavor violating decays and found that the existing strong bounds on $\mu \to 3e$ and $\mu \to e\gamma\gamma$ severly constrain two-body lepton flavor violating decays of vector bosons [J/ψ, Υ, and Z^o] or pseudoscalars [π^o, η] into $\mu^\pm e^\mp$ final states. However the bounds derived in Ref.[4] can be avoided if there is a kinematical suppression or as a result of some cancellations. Searching for lepton flavor violating decays of vector bosons such as J/Ψ remains a worthwhile experimental challenge.

BES started one year ago[5] and has been working on an experiment of searching for $J/\Psi \to e^\mp \mu^\pm$. They will publish their result officially in the near future.

2 Single D meson production in J/Ψ decays

Kinematically J/Ψ can not decay into D meson pairs, however it is able to decay into single D meson. In the standard model, these Cabbibo suppressed and/or favored weak decays have a typical branch ratio $\sim 10^{-8}$ or smaller, which is unobservable and because of which these processes serve as a probe of new physics. Recently Datta, O'Donnell, Pakvasa and I[6] have studied the possibility of searching for new flavor changing neutral current in the decay of J/Ψ. The purpose

of the study is to answer whether new physics can enhance sufficiently for the processes to be observable in the near future experiments. We first perform a model independent analysis, then examine the predictions of the models, such as TopColor models, minimal sypersymmetric standard model with R-parity violation and the two Higgs doublet model. We found that the branch ratio of $J/\Psi \to D/\overline{D}X_u$ could be as large as 10^{-5}[6].

Experimentally with BES-II data $\sim 8 \times 10^6 J/\Psi$, BES found no signal of single D production in J/Ψ decays, and put limits on decay rates [7](at 90% C.L.): $Br(J/\Psi \to \overline{D}^0\rho^0) \leq 1.25 \times 10^{-5}$; $Br(J/\Psi \to D_s^+K^-) \leq 2.8 \times 10^{-5}$, and $Br(J/\Psi \to D/\overline{D}X_u) \leq 1.7 \times 10^{-4}$. These are preliminary results.

Next year BES will have collected $\sim 5 \times 10^7 J/\Psi$. The upper limit on $Br(J/\Psi \to D/\overline{D}X_u)$ is expected to be reduced to $\sim 3 \times 10^{-5}$, which is very close to the theoretical prediction. If there is still no signal found, it will put some constraints on models beyond the standard electroweak theory[6].

3 CP violation in J/Ψ decays

The origin of CP violation remains one of the outstanding problems in particle physics and cosmology. To pin down the sources and nature of CP violation in or beyond the Cabbibo-Kabayashi-Maskawa model, it would be necessary to consider different observations of CP violation in different channels from the K system, B sysytem, *etc.* The reaction of interest at BES is[8]

$$e^+(p) + e^-(-p) \to J/\Psi \to A(q_-) + \bar{B}(q_+) + X \quad , \quad (5)$$

where A ($\bar{B}$) are charged particles, for instance $\pi^\pm$ in the processes of three or five pions decay of the J/Ψ, and p, q_- and q_+ are corresponding momentum in the laboratory frame. Define CP/T-odd operator

$$O_1 = \frac{\vec{p}\cdot\vec{q}_+ \times \vec{q}_-}{|\vec{p}\cdot\vec{q}_+ \times \vec{q}_-|} \quad . \quad (6)$$

If there exists CP violating interaction in J/Ψ decays, one would expect a non-vanishing expectation value of operator O_1. Theoretically there could be many sources responsible for the CP violation in the process. One of them is the Chromo-dipole moment of the charm quark $ig_c\frac{d_g}{2}\overline{c}\sigma_{\mu\nu}\gamma_5\lambda^a cG_a^{\mu\nu}$ where d_g has $[\text{mass}]^{-1}$ dimension and the g_c the strong interaction coupling constant.

Consider the process of three pion decay of the J/Ψ. Its branch ratio is around 1.5%. With $10^8 \sim 10^9 J/\Psi$ at BEPC II there will be around $10^6 \sim 10^7$ available for the analysis of CP violation. To estimate the experimental sensitivities to d_g, let us consider only the statistical uncertainties. Neglecting the systematical uncertainties one expects to be able at BES to probe for d_g as small as $(1/\sqrt{10^6 \sim 10^7}) \times (1/m_c) \leq 10^{-17} cm$.

One can easily construct different kind of CP/T-odd operators of three momentum products (p, q_-, q_+) for the analysis of CP violation in J/Ψ decays. For instance,

$$O_2^{ij} \sim (\vec{q}_+ - \vec{q}_-)^i \cdot (\vec{q}_+ \times \vec{q}_-)^j + (i <-> j). \quad (7)$$

The initial electron and/or positron beams are not polarized at BEPC, otherwise one would be able to construct observables with the initial polarization vector $\vec{\sigma}$,

$$O_3 \sim \vec{\sigma} \cdot \vec{q}_- \times \vec{q}_+. \quad (8)$$

There has been proposal to measure CP violation in $e^+e^- \to J/\Psi \to \Lambda\bar{\Lambda}$. With a large sample of J/Ψ, one expects to probe for and put a strong bound on the electric dipole moment of Λ[9].

4 Conclusion and comments

In this paper I have concentrated on three kind of processes to probe for new physics in the decay of J/Ψ. There are some other rare decay modes which are interesting, but not reviewed. For instance, with a large sample of J/Ψ, it is possible and physically interesting to search for Goldstone or

Pseudo-Goldstone J, such as Axion in the process

$$J/\Psi \to \gamma + J \qquad . \qquad (9)$$

Another example is the invisible decay of J/Ψ investigated by Chang, Lebedev and Ng[10] recently in models with extra Z-bosons, minimal sypersymmetric standard model with R-parity violation and decays into Goldstinos. The third example is provided by Bijnen and Maul[11], who recently have calculated in detail the branch ratio of J/Ψ decay into photon + missing energy in the popular theory these days with large extra dimension. They found that the branch ratio could be as large as 10^{-5}, which is measurable at BES. Before conclusion, we point out that even though we focus our discussions here on J/Ψ decays, it is quite easy to apply the studies in this paper for Ψ' and Υ system[12].

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